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Electrical Engineering

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STUDY OF RESISTANCE OF GROUNDS

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BY

HERBERT EUGENE BELL
AND
HARRY HARMON COE

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1910

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HERBERT EUGENE BELL and HARRY HARMON COE

ENTITLED STUDY OF RESISTANCE OF GROUNDS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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APPROVED: Ernst Berg

HEAD OF DEPARTMENT OF ELECTRICAL ENGINEERING

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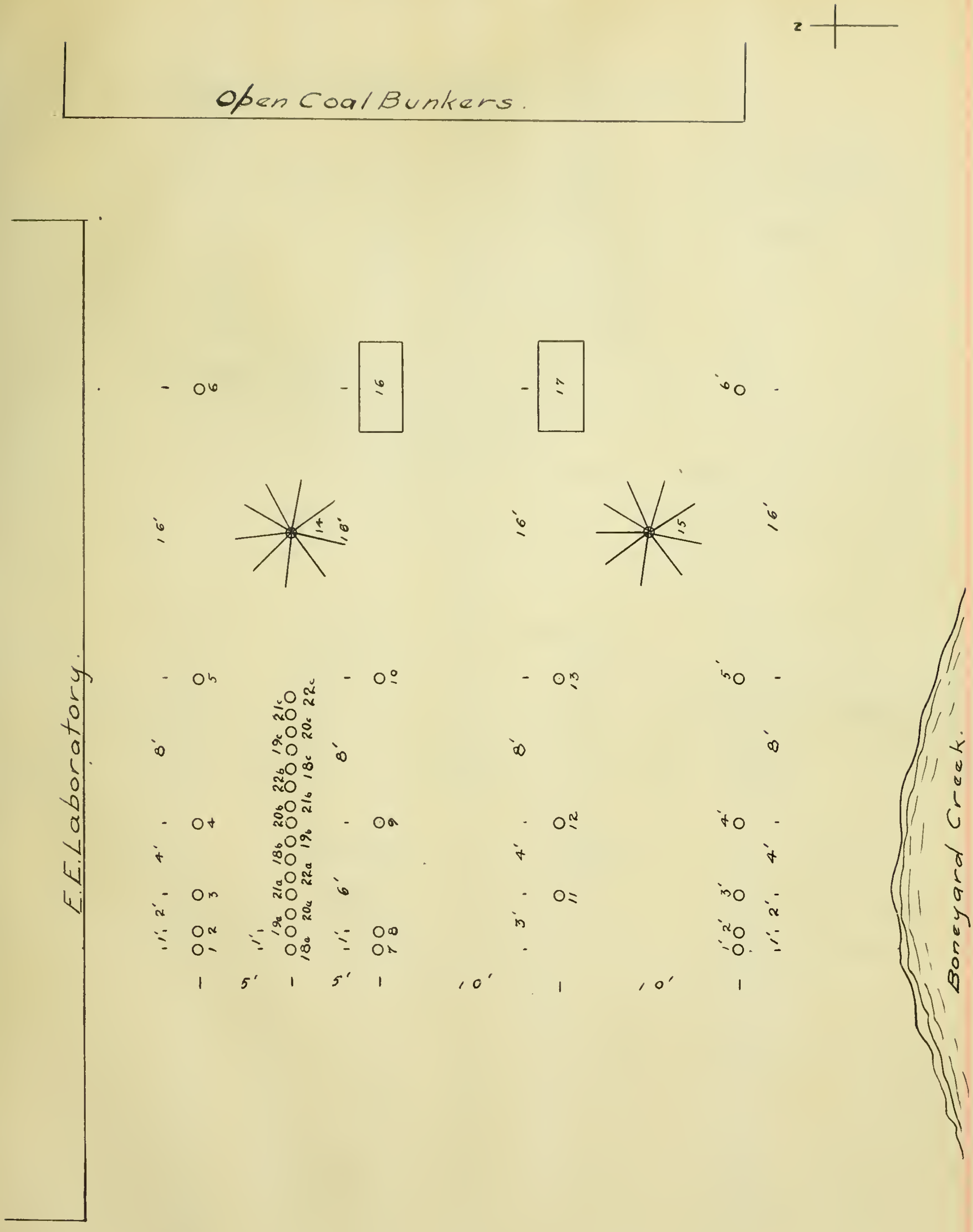
The authors of this thesis are greatly indebted to Mr. A. B. Gates, B.S. for his assistance and suggestions in compiling this data.

INTRODUCTION

With the development of electrical energy for power and illumination during the past century, the problem of the grounded neutral and earth return has been widely discussed. However, very little research work has been done along this line, and practically no reliable data can be obtained on the resistance of grounds.

In the past discussions of earth circuits, few references have been made to the most important phase, that of the connection to earth.

This paper is an investigation of the resistance of earth connections and the ground circuit under various conditions. In the contents presented, the aim has been to offer reliable information upon the most efficient ground connection and the variation of earth resistance under the several conditions.


N
Open Coal Bunkers.
E.E. Laboratory.
Boneyard Creek.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18a 19a 20a 21a 22a
18b 19b 20b 21b 22b
18c 19c 20c 21c 22c
1'
2'
3'
4'
5'
6'
8'
16'
10'

DESCRIPTION OF PLOT OF GROUND.

For this experimental work the plot of ground lying directly south of the Electrical Engineering Laboratory was chosen. The plot is, as shown in sketch, about fifty feet on a side, and is nearly level in contour. The earth is partly natural, and partly made. Black loam forms the upper two and one-half to three feet; that near the surface showing signs of having been graded in. Below the loam is a stratum of yellowish-blue clay from six to eight inches in depth. Beneath this, the soil was common blue clay.

DESCRIPTION OF APPARATUS.

The grounds were laid out according to sketch shown, and the following arrangement of ground connections chosen.

Number	Kind of Terminal	Length in Feet.	Kind of Point.
1	Pipe	4	Sharpened
2	"	4	Plain
3	"	4	"
4	"	4	"
5	"	4	"
6	"	4	"
1'	"	4	"
2'	"	4	"
3'	"	4	"
4'	"	4	"

Number	Kind of Terminal	Length in Feet.	Kind of Point.
5	Pipe	4	Sharpened
6	"	4	"
7	"	1	Plain
8	"	2	Sharpened
9	"	6	Plain
10	"	8	"
11	"	4	"
12	"	6	"
13	"	8	"

Number 14 is a pipe four feet long, plain point, with nine number four B and S gage wires three feet in length, fanned out from the bottom.

Number 15 is a four foot pipe, plain point, with nine number twelve B and S gage wires three feet in length, fanned out from the bottom.

Number 16 is a copper plate, 2-1/2 by 5 feet by 1/64 inch in thickness, which was buried at a depth of four feet in coke.

Number 17 is a copper plate, 2-1/2 by 5 feet by 1/64 inch in thickness, buried in earth at a depth of four feet.

The pipes used were the common wrought iron pipes, not galvanized, found on the market in standard sizes.

Work was commenced on the placing of the terminals during the latter part of January, with the frost still in the ground. Considerable difficulty was met with in driving these pipes, due to the condition of the ground, and to the points of the pipes,

in most cases, being plain. Since it was desired to have the same surface for each pipe, care was taken to drive all pipes in as nearly the same conditions as possible.

Pipe number 5 was split in driving, so was drawn. The hole was then filled, tamped, and a new pipe driven.

Pipes number 1, 2, 3, 4, 5, 6, and 1', 2', 3', 4', 5', and 6' were all driven on the same day, but the ground near the "Boneyard creek" was frozen deeper than that near the Laboratory and may account for the variation in the resistance of these series of pipes.

Pipe number 13 struck a rock in being driven, so the contact may be influenced by this.

In locating number 14 and 15, four foot holes were dug, the pipe and fan put in place, and the earth replaced, tamped, and watered.

The copper plates, number 16 and 17, were fitted with terminals by soldering number eight B and S gage copper wire to the centers of the longer sides, near the outer edges, and running them across to the center of the plate, being soldered the entire length. The joints were covered with two coats of paint, acid and water proof, to prevent electrolytic action. They were buried in the manner of number 14 and number 15, except that seven bushels of coke screenings were packed around number 16, giving a three inch layer of coke all about the plate.

Pipes number 14, 15, 16, and 17, at a depth of four feet, lie in the stratum of blue clay mentioned above.

Pipes number 10, 11, and 12 were driven to be used for the salt tests, but data was first taken on them as for other pipes.

The pipes numbered from 18a to 22c were driven on April 8, 1910. They are spaced one foot apart, are all four feet in length, and range in sizes as follows:

Numbers.	Diameter.
18a, 18b, 18c	1/4 inch.
19a, 19b, 19c	1/2 inch.
20a, 20b, 20c	1 inch.
21a, 21b, 21c	2 inches.
22a, 22b, 22c	3 inches.

A hole was tapped near the upper edge of each pipe, and a pipe plug, bearing about six inches of number twelve copper wire, screwed in. A brass terminal was soldered to the ends of the wires, similar to that on the end of a voltmeter lead.

Three leads of weather-proof copper wire, size number eight, each thirtyfive feet long, were used. In one, a terminal similar to that on the pipes was fastened at the center point, for use in parallel connections.

Terminals of brass were made and soldered to one end of each of the leads to receive the pipe terminals and insure good contact.

METHODS OF OPERATION AND

DESCRIPTION OF TESTS

The method used in these tests is very simple, and the theory involves only the use of Ohm's Law, $I = \frac{E}{R}$, where I is the current flowing, E is the electro-motive force impressed, and R is

the resistance. Alternating current was chosen for the testing to eliminate electrolytic action. The inductance of the earth is so small that it may be considered as negligable. The University sub-station in the Laboratory was used as a source of power, the normal E. M. F. of the A. C. generator being 440 volts at 60 cycles. Through the use of transformers, and the regulation of the field by rheostats from the test table, any desired voltage up to 440 was obtained. A storage battery was used for field excitation. On the test table were the rheostats, a voltmeter, range 0 - 60 - 120 volts with a three to one multiplier attached, and an ammeter, range 0 - 10. amperes.

The water-piping system of the University was considered as being the most available general ground connection, and a terminal was fastened to a water pipe.

The first test was made with one end grounded to this pipe, the other terminal being attached in turn to each of the ground connections. From this data, the desirable current to be used with the available range of E. M. F. was chosen. All other tests were made with this chosen value - six amperes - flowing.

Throughout the several weeks the following data was taken, readings of E. M. F. and current being recorded:

(1) Ground to pipes, (series).
Ground to fanned pipe, (series).
Ground to plates, (series).
Ground to pipes, (parallel).
Ground to fanned pipe, (parallel).
Ground to plates, (parallel).

(2) Pipe to pipe, (series).

Pipe to fanned pipe, (series).

Pipe to plates, (series).

(3) Ground to pipes, (series), before and after salting.

The process of salting was as follows:- A hole about one foot in diameter, and eight inches deep, was dug around each pipe used in this test, and ten pounds of coarse salt placed in each hole. Water was then poured in the hole until it was filled, and a level was maintained while the test readings were taken. Readings were recorded every one-half minute for ten minutes, then every five minutes for twenty minutes, and finally, every thirty minutes for three hours. This test was applied to pipes number 11, 12, and 13, on March 31, 1910.

The following day the hole was filled with dirt, and readings were taken from then on for these pipes the same as for all others.

ELIMINATION OF ERRORS

In taking the data several readings were taken for each connection and the mean used in each case, as final. Corrections were made for the voltmeter and ammeter readings, and the value of resistance computed. From this value the resistance of the leads was subtracted in each case.

Samples of data taken, and computed average values of resistance over the entire period of testing, follow. The curves have been plotted from the average values, and show the results of the experimental work.

OUTLINE OF CURVES

Curve 1.

(a) Variation of resistance with duration of time.

(b) Comparison of resistance with plates in earth and plates in coke.

(c) Comparison of resistance between plain pipes, pipes fanned at bottom, and plates.

Curve 2.

Variation of resistance with distance between pipes.

Curve 3.

Variation of resistance with length of pipe.

Curve 4.

Variation of resistance with size of pipe.

Curve 5.

Variation of resistance, with distance between pipes in parallel.

Curve 6.

Variation of resistance with time after salting.

Variation of resistance between pipes, plain and salted.

Curve 7.

Uniformity of resistance with constant distance between pipes, to ground.

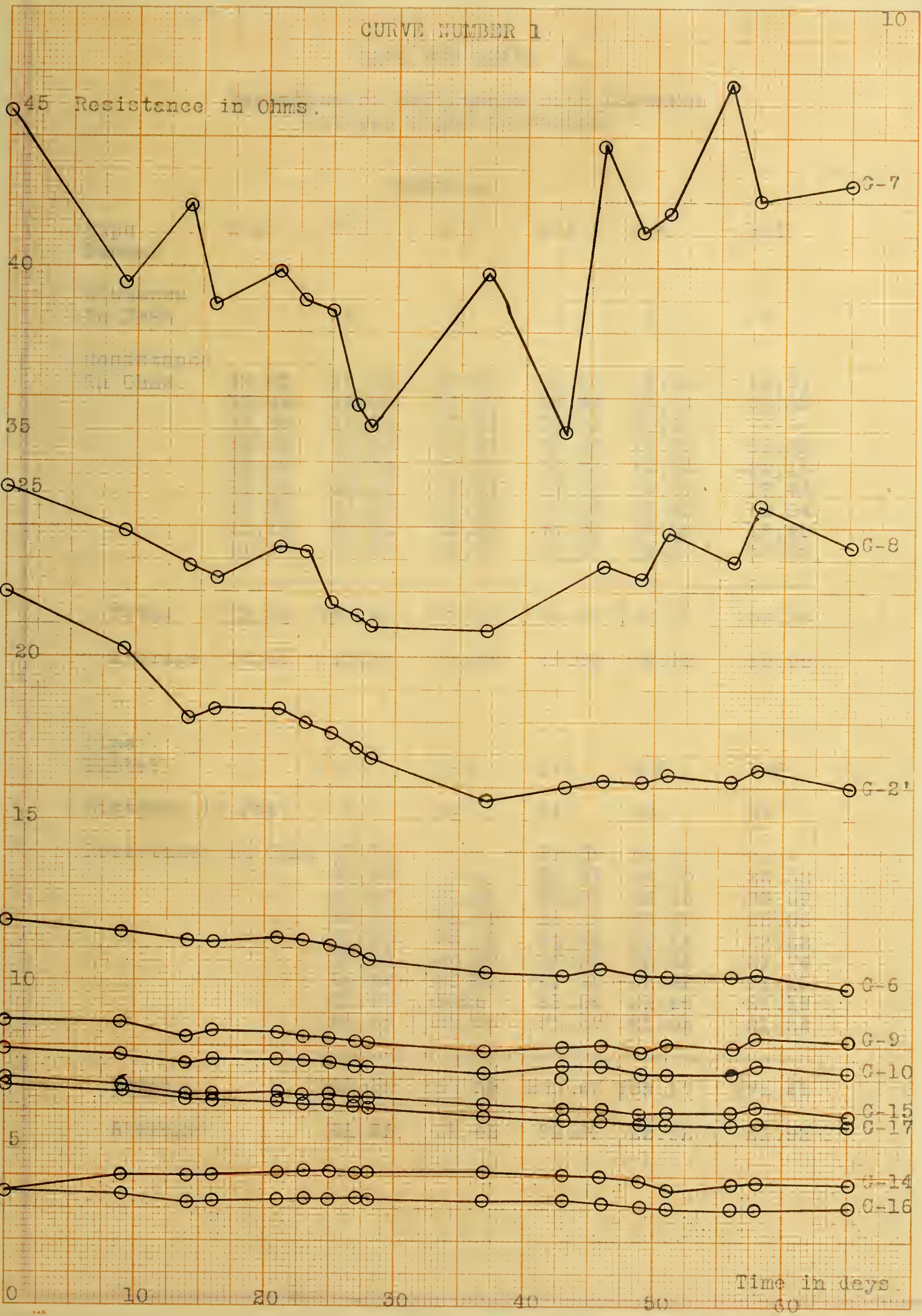
DATA FOR CURVE 1.

Variation of Resistance with Time.

Ground to Pipe Number	7	8	2'	6	9
Time in Days					
Start	44.84	25.14	21.94	11.84	8.76
9	39.59	23.89	20.26	11.53	8.64
14	41.94	22.11	18.09	11.23	8.34
16	37.94	22.44	18.38	11.23	8.41
21	39.99	23.44	18.44	11.56	8.44
23	39.04	23.30	17.98	11.29	8.33
25	38.72	21.64	17.76	11.15	8.26
27	35.74	21.24	17.25	10.92	8.12
28	35.12	21.04	16.92	10.74	8.17
37	39.97	20.93	15.63	10.30	7.92
43	34.97	20.24	16.09	10.39	8.06
46	43.68	22.84	16.30	10.44	8.06
49	41.02	22.52	16.20	10.22	7.90
51	41.66	23.83	16.51	10.36	8.18
56	45.64	24.09	16.30	10.22	7.95
58	42.14	24.79	16.60	10.30	8.37
65	42.54	23.55	16.19	9 .97	8.26

Ground to Pipe Number	10	15	17	14	16
Time in days.					
Start	7.79	6.89	6.89	3.41	3.44
9	7.75	6.74	6.68	4.03	3.44
14	7.54	6.55	6.42	3.96	3.25
16	7.64	6.55	6.36	4.01	3.31
21	7.65	6.65	6.42	4.10	3.32
23	7.58	6.41	6.33	4.13	3.38
25	7.51	6.51	6.20	4.16	3.39
27	7.38	6.49	6.17	4.12	3.37
28	7.42	6.42	6.16	4.16	3.30
37	7.29	6.23	5.88	4.07	3.31
43	7.44	6.12	5.76	4.05	3.34
46	7.40	6.10	6.76	4.03	3.27
49	7.20	5.95	5.79	3.86	3.07
51	7.32	6.04	5.73	3.77	3.02
56	7.22	6.03	5.62	3.83	3.09
58	7.54	6.07	5.72	3.97	3.17
65	7.36	5.90	5.63	3.92	3.16

CURVE NUMBER 1



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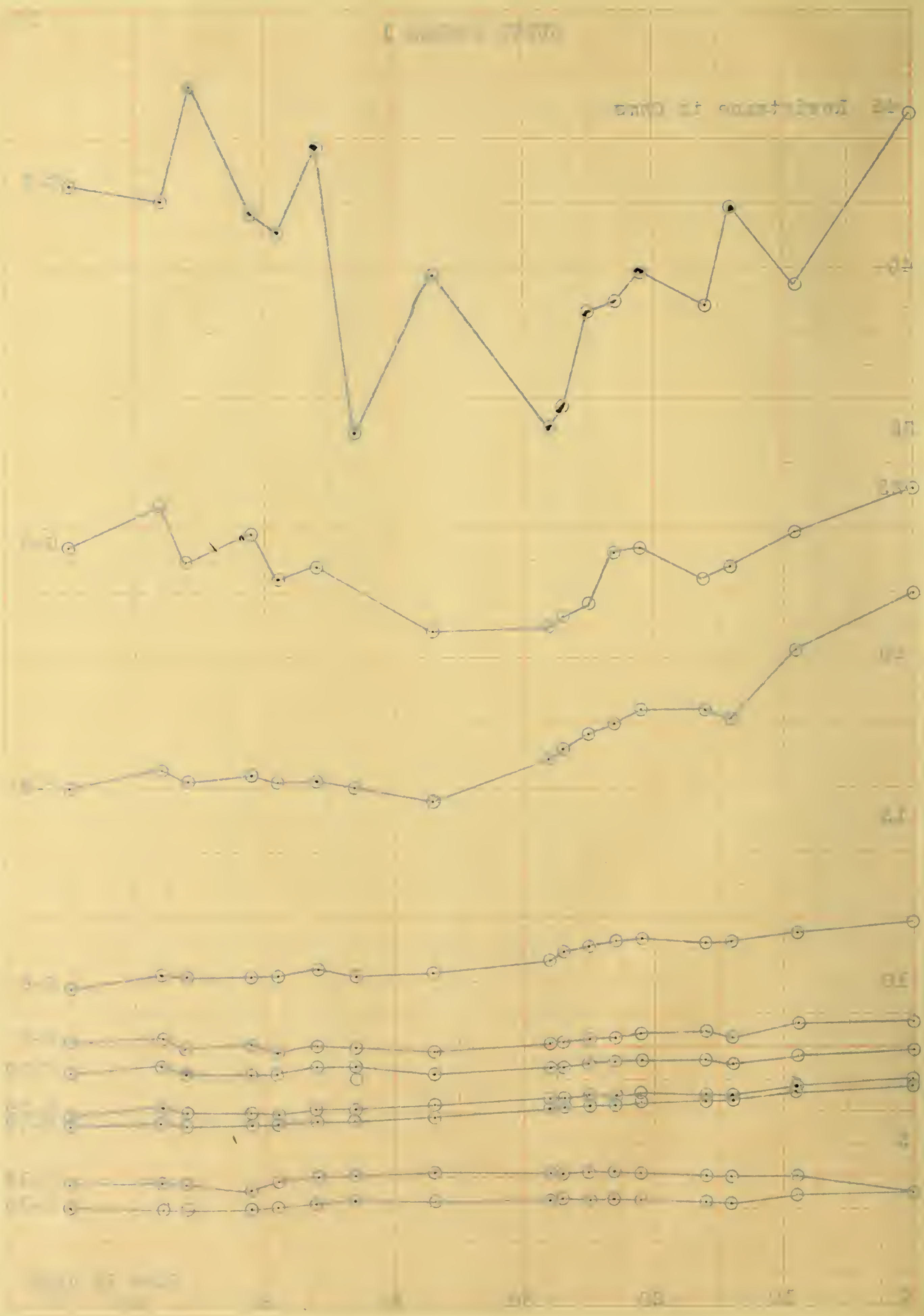

DATA FOR CURVE 2.

Variation of Resistance with Distance Between Pipes in Series.

CURVE A.

Pipe Number	1-2	2-3	1-3	3-4	2-4	1-4
Distance in Feet	1	2	3	4	6	7
Resistance in Ohms.	12.83	15.44	16.99	18.14	19.54	19.91
	12.99	15.74	16.70	18.44	18.14	20.22
	13.38	16.04	17.49	19.12	20.44	-----
	12.82	15.69	17.09	18.44	19.89	22.02
	12.89	15.54	16.92	18.24	19.59	22.15
	12.54	15.26	16.45	17.88	19.29	19.44
	12.30	14.77	16.05	17.40	18.63	19.04
	12.16	14.52	15.84	17.09	18.40	18.69
	11.98	14.39	15.58	16.92	18.20	18.39
Total	113.89	137.39	149.11	161.67	172.12	159.86
Average	12.65	15.26	16.56	17.96	19.12	19.99

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Pipe Number	4-5	3-5	5-6	4-6	1-6
Distance in Feet	8	12	16	24	31
Resistance in Ohms	23.11	----	22.35	22.16	----
	21.59	----	22.99	22.15	22.32
	21.84	22.09	23.04	23.16	23.59
	21.28	21.44	23.19	22.29	22.05
	21.90	22.05	22.65	22.64	22.22
	21.04	22.40	22.93	21.85	21.74
	20.42	20.62	21.32	21.42	21.16
	20.60	2084	21.58	21.46	21.19
	20.44	20.65	21.27	21.04	21.24
Total	192.22	150.09	200.41	198.17	175.41
Average	21.36	21.45	22.26	22.02	21.92

DATA FOR CURVE 2.

Variation of Resistance with Distance Between Pipes in Series.

CURVE B.

Pipe Number	1'-2'	2'-3'	1'-3'	3'-4'	2'-4'	1'-4'
Distance in Feet	1	2	3	4	6	7
Resistance in Ohms.	20.09	25.35	27.94	28.36	30.21	30.94
	20.52	25.69	28.44	28.66	30.53	31.24
	20.74	26.04	28.76	28.94	30.94	-----
	20.04	25.24	27.64	28.04	29.94	30.74
	20.47	25.28	28.09	28.30	29.94	30.86
	19.83	24.72	27.45	27.64	29.92	30.25
	19.42	23.94	26.26	26.74	28.42	-----
	19.64	22.42	26.39	26.39	28.14	29.24
	19.34	23.54	25.49	26.02	27.75	28.82
Total	180.09	222.22	246.46	249.09	265.79	212.09
Average	20.09	23.58	27.38	27.68	29.53	30.29

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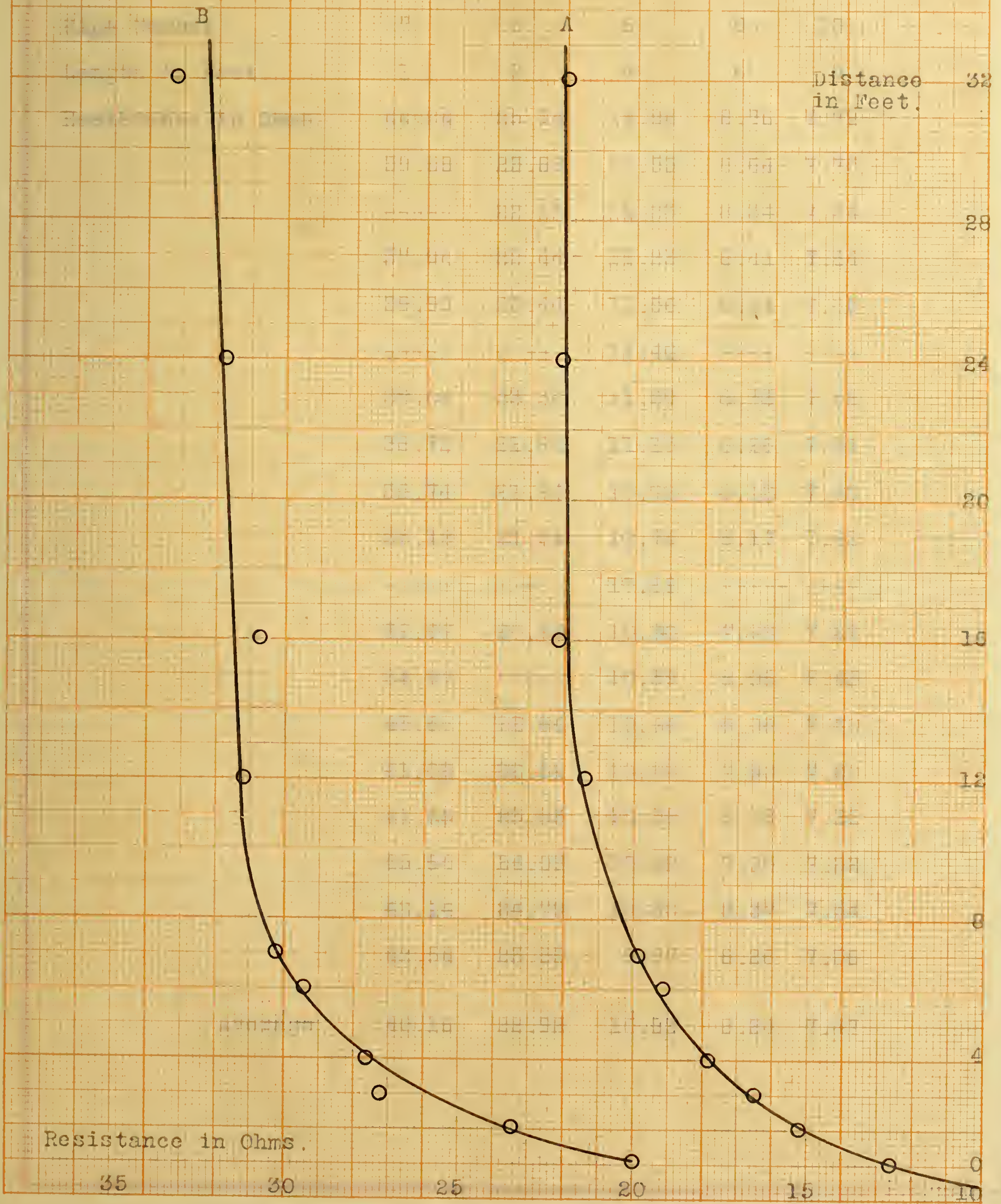
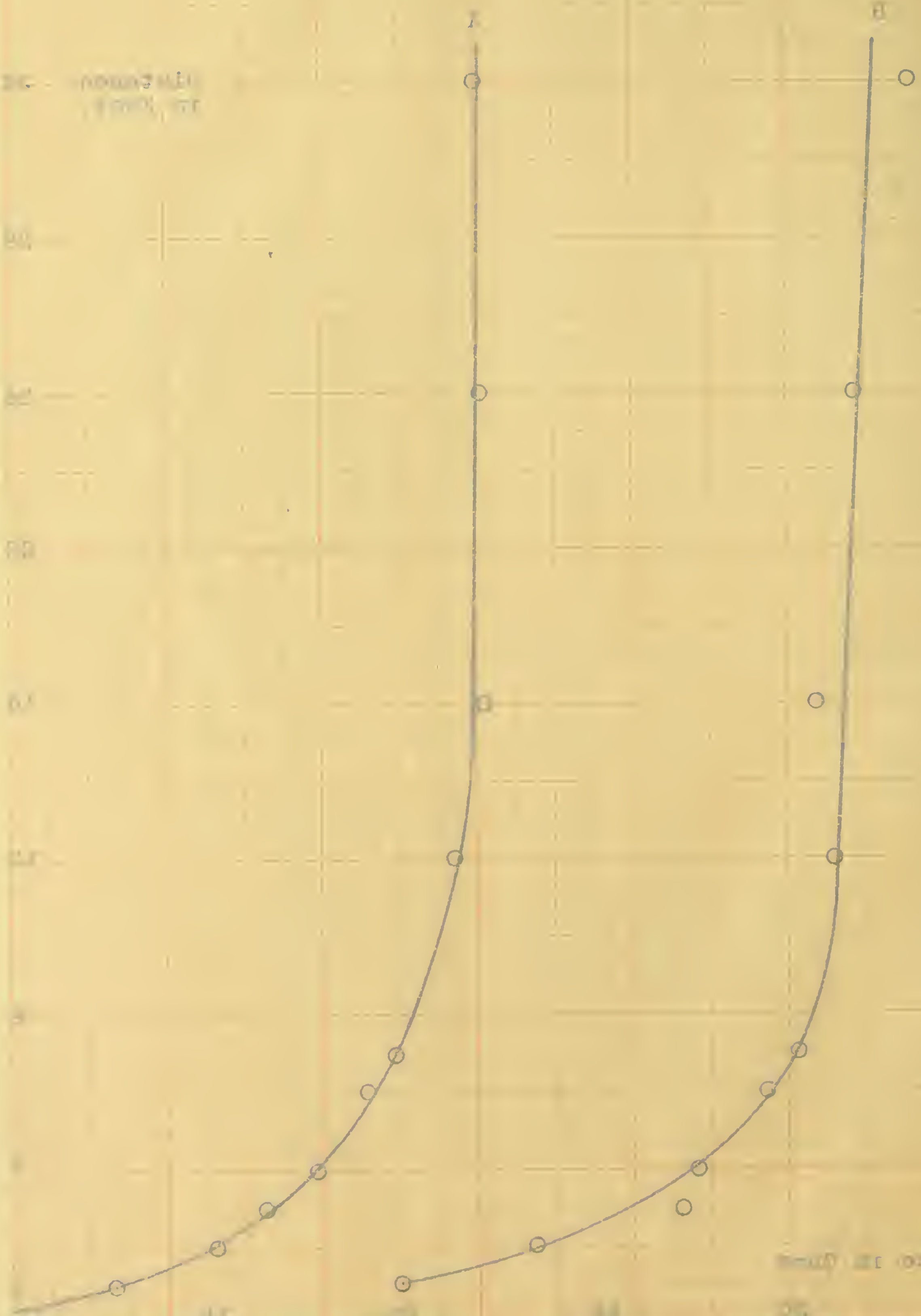
Pipe number	4'-5'	3'-5'	5'-6'	4'-6'	1'-6'
Distance in Feet	8	12	16	24	31
Resistance in Ohms.	30.22	-----	31.74	32.73	34.34
	30.44	-----	36.97	32.94	34.39
	30.24	32.89	31.36	32.84	34.70
	29.94	31.74	31.34	32.25	33.74
	31.74	32.14	31.34	32.34	33.74
	29.22	31.39	30.66	31.74	33.29
	28.36	30.54	29.82	30.84	32.14
	28.09	30.24	29.46	30.44	31.82
	27.74	29.84	29.14	30.24	31.56
Total	265.99	218.78	276.85	286.36	299.82
Average	29.56	31.25	30.76	31.81	33.31

CURVE NUMBER 2

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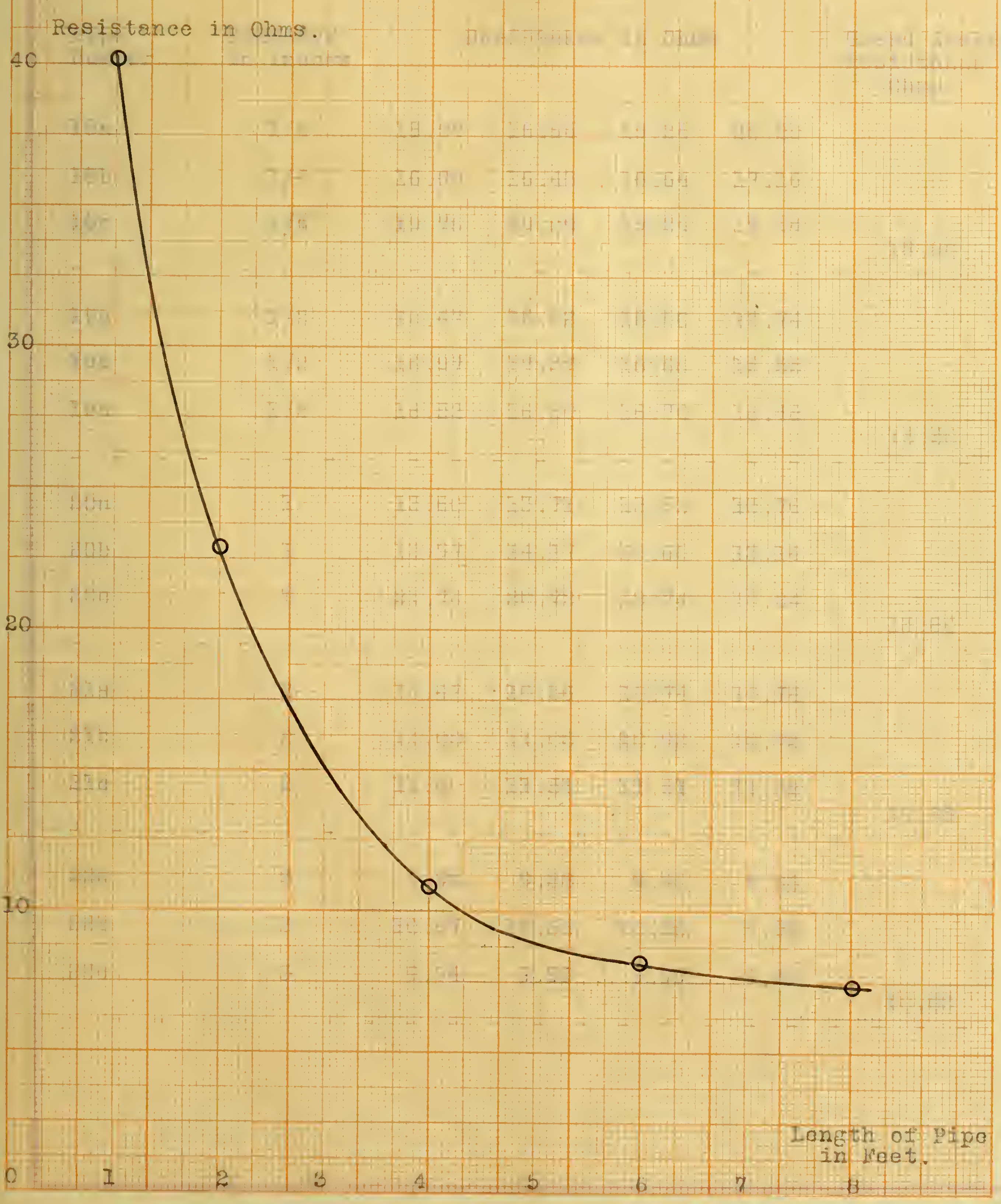
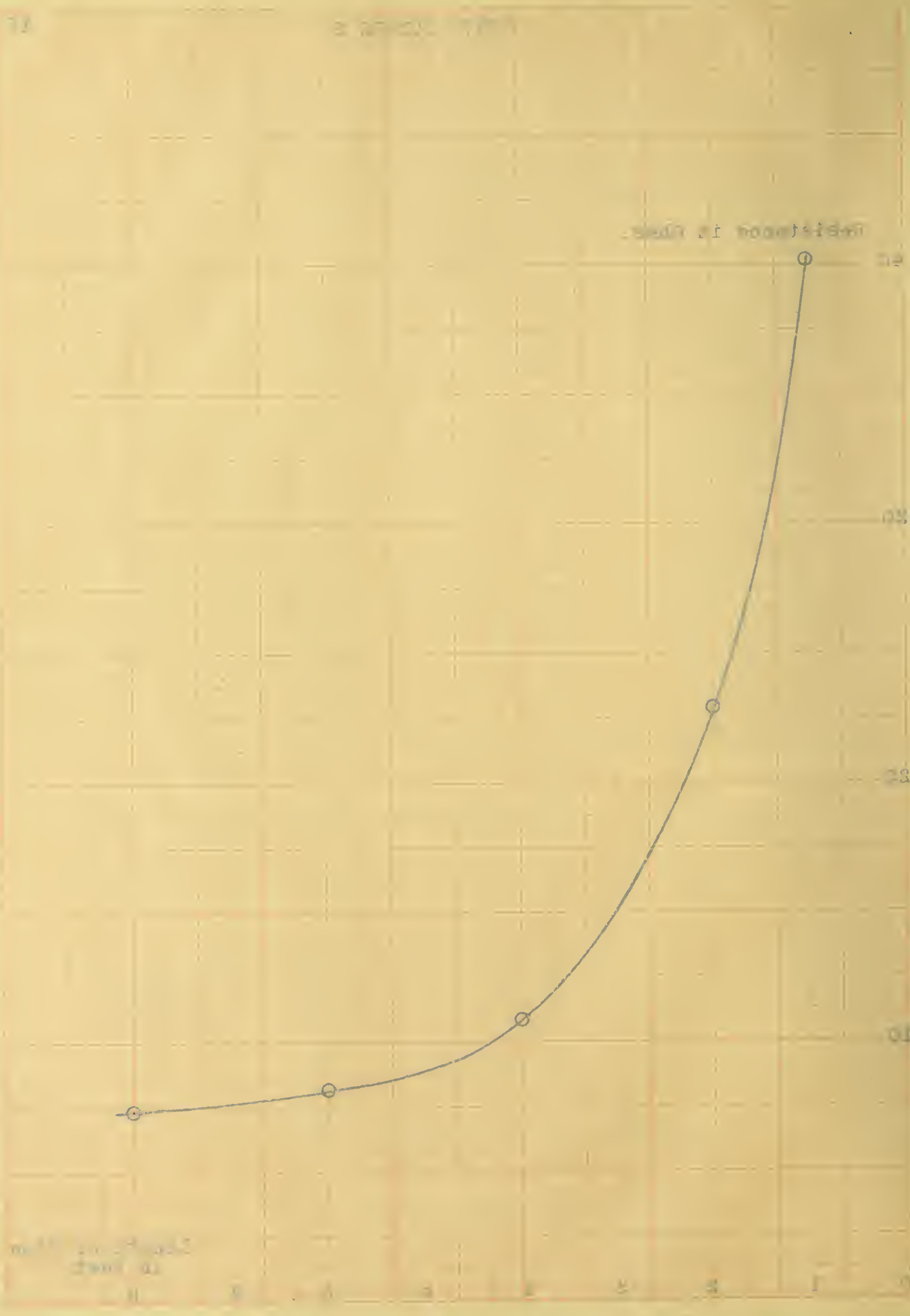
DATA FOR CURVE 3.

Variation of Resistance with Length of Pipe.

Pipe Number.	7	8	6	9	10
Length in Feet.	1	2	4	6	8
Resistance in Ohms.	44.84	25.14	11.84	8.76	7.79
	39.58	23.89	11.53	8.64	7.75
	-----	22.11	11.23	8.34	7.54
	37.94	22.44	11.23	8.41	7.64
	39.99	23.44	11.56	8.44	7.65
	-----	-----	11.40	----	----
	39.04	23.30	11.29	8.33	7.58
	38.72	21.64	11.15	8.26	7.51
	35.74	21.24	10.92	8.12	7.38
	35.12	21.04	10.74	8.17	7.42
	-----	-----	10.69	-----	----
	39.97	20.93	10.30	7.92	7.29
	34.97	-----	10.39	8.06	7.43
	43.68	22.84	10.44	8.06	7.40
	41.02	22.52	10.22	7.90	7.20
	41.66	23.83	10.36	8.18	7.32
	45.64	24.09	10.22	7.95	7.22
	42.14	24.79	10.30	8.37	7.54
	42.54	23.55	9.97	8.26	7.36
Average	40.16	22.92	10.83	8.24	7.47

CURVE NUMBER 3



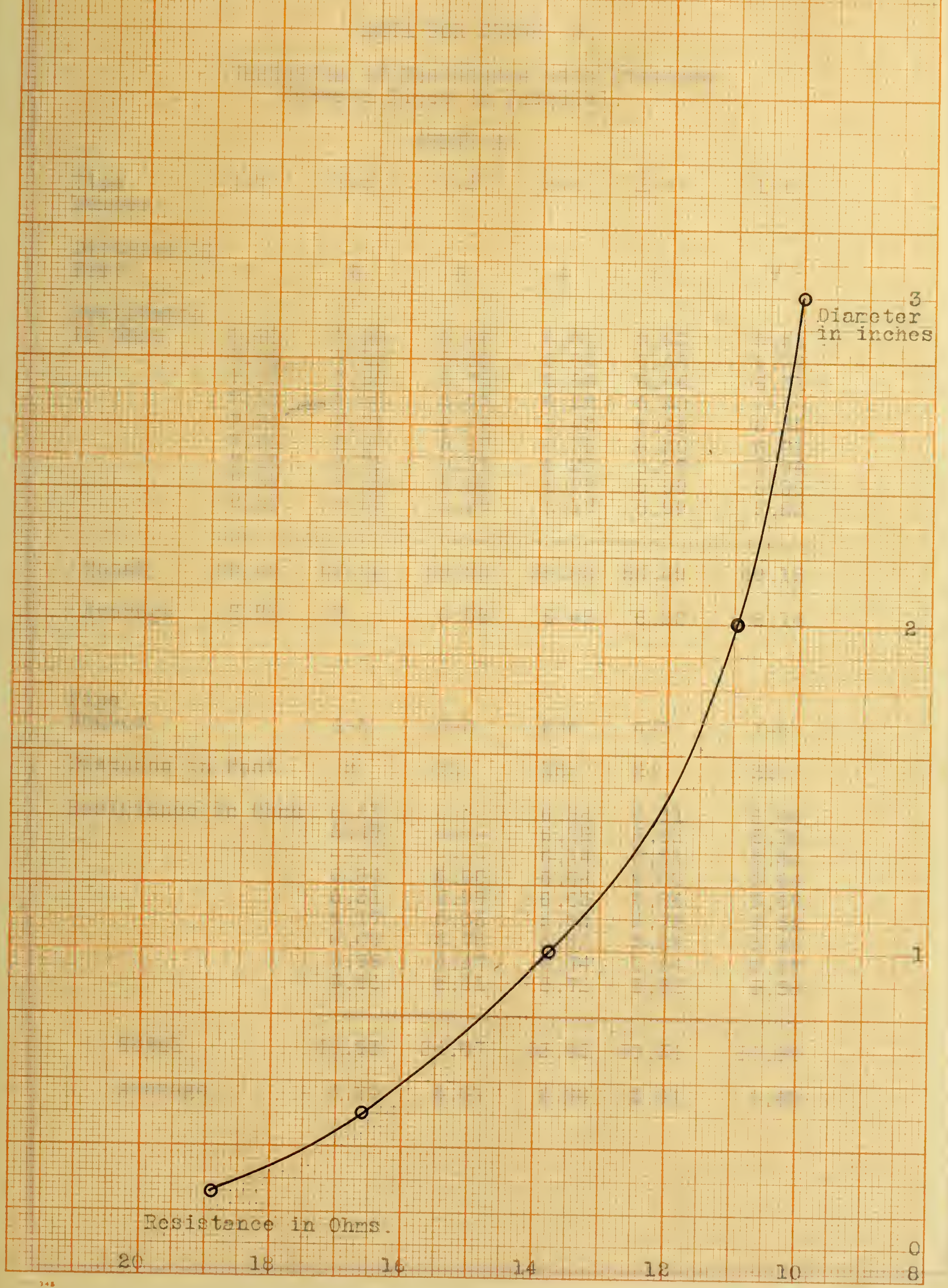


DATA FOR CURVE 4.

Variation of Resistance with Size of Pipe.

Pipe Number	Diameter in Inches	Resistance in Ohms				Grand Average Resistance in Ohms.
18a	1/4	18.07	16.64	18.24	20.29	
18b	1/4	16.00	16.48	16.64	17.16	
18c	1/4	19.76	19.09	19.24	19.14	18.90
19a	1/2	15.47	15.52	15.50	15.74	
19b	1/2	16.97	17.37	16.68	15.55	
19c	1/2	16.52	16.50	16.70	16.48	16.58
20a	1	13.60	13.71	13.52	13.76	
20b	1	13.97	14.17	13.65	13.14	
20c	1	21.74	20.72	18.74	18.24	13.80
21a	2	10.47	10.56	10.74	10.74	
21b	2	11.00	11.06	10.92	10.73	
21c	2	11.40	11.51	11.51	11.22	10.99
22a	3	9.94	9.88	9.95	9.96	
22b	3	10.67	10.66	10.26	9.98	
22c	3	9.94	9.95	9.99	9.49	10.03

CURVE NUMBER 4.



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DATA FOR CURVE 5.

Variation of Resistance with Distance Between Pipes in Parallel.

CURVE A

Pipe Number	1-2	2-3	1-3	3-4	2-4	1-4
Distance in Feet	1	2	3	4	6	7
Resistance in Ohms	8.00	7.30	6.92	6.81	6.62	6.51
	8.04	7.13	6.80	6.62	6.44	6.34
	7.96	7.20	6.78	6.66	6.44	6.31
	7.88	7.05	6.63	6.52	6.30	----
	7.84	7.01	6.69	6.42	6.44	6.35
	7.46	6.88	6.47	6.36	6.20	6.01
	7.48	6.76	6.37	6.26	6.07	5.94
	7.37	7.05	6.32	6.19	5.99	5.86
	7.51	6.62	6.27	6.17	5.99	5.83
Total	69.44	63.00	59.25	58.08	56.49	49.15
Average	7.71	7.	6.58	6.48	6.28	6.14

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Pipe Number	4-5	3-5	5-6	4-6	1-6
Distance in Feet	8	12	16	24	31
Resistance in Ohms	6.61	----	6.34	6.11	6.04
	6.47	----	6.18	6.01	5.86
	----	----	6.14	6.01	5.84
	6.34	6.00	6.04	5.88	5.64
	6.31	5.99	6.03	5.86	5.69
	6.17	5.85	5.94	5.72	5.52
	6.08	5.75	5.82	5.69	5.48
	5.99	5.67	5.74	5.54	5.37
	5.96	5.61	5.72	5.52	5.38
Total	49.93	34.87	53.95	59.34	50.82
Average	6.24	5.81	5.98	5.81	5.65

DATA FOR CURVE 5.

Variation of Resistance with Distance Vetween Pipes in Parallel.

CURVE B

Pipe Number	1'-2'	2'-3'	1'-3'	3'-4'	2'-4'	1'-4'
Distance in feet	1	2	3	4	6	7
Resistance in Ohms	13.57	12.27	11.73	11.04	10.49	10.87
	13.60	12.32	11.78	11.06	10.50	10.40
	13.76	12.42	11.92	11.20	10.66	10.66
	13.45	12.16	11.62	10.84	10.32	10.30
	13.36	12.08	11.58	11.05	10.33	10.30
	13.10	11.86	11.40	10.69	10.14	10.05
	12.76	11.52	11.09	10.40	9.90	9.82
	12.62	11.41	10.96	10.32	9.84	9.77
	12.44	11.28	10.82	10.23	9.71	9.64
Total	118.66	107.32	102.90	96.83	91.89	91.81
Average	13.18	11.92	11.43	10.76	10.21	10.20

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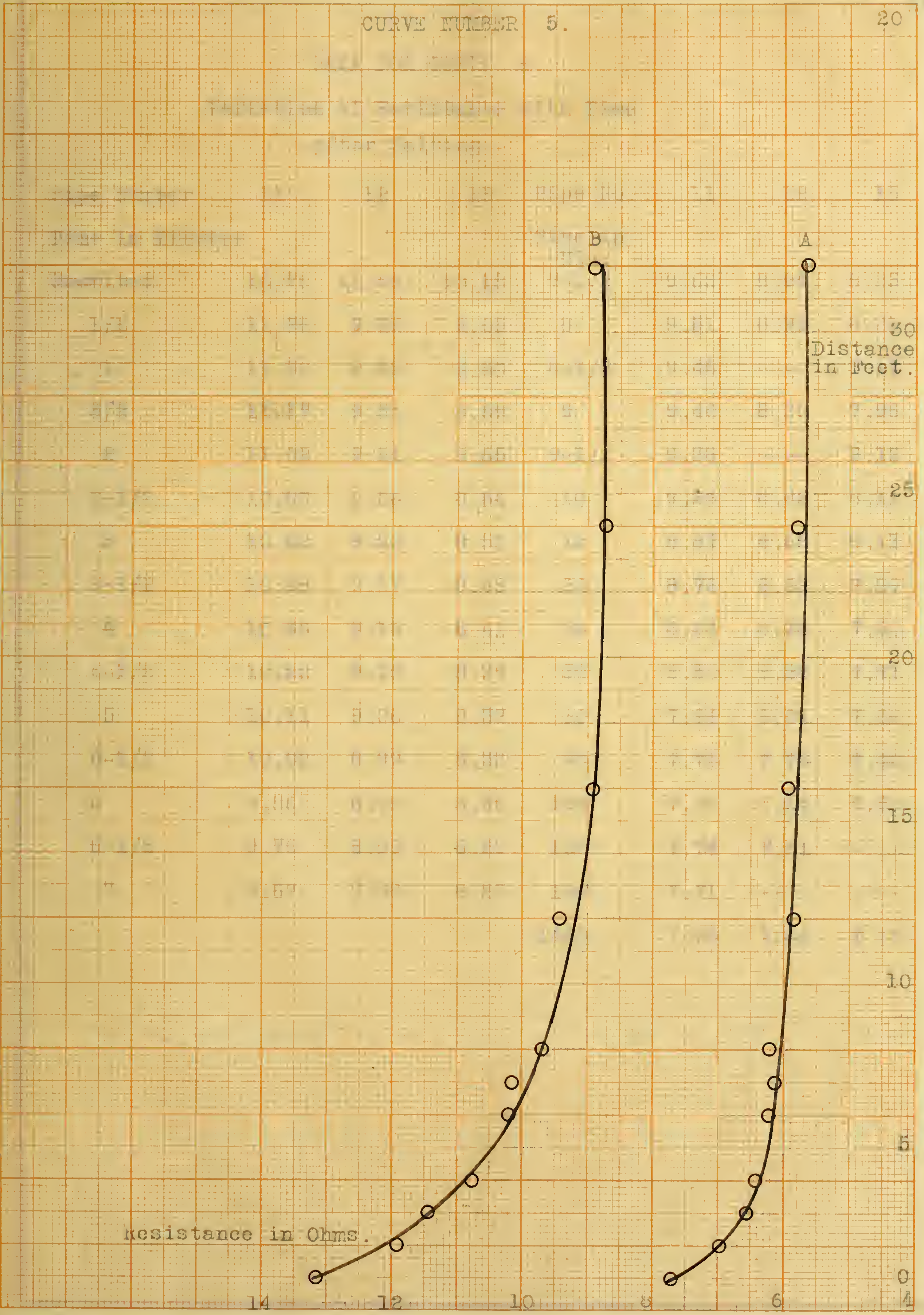
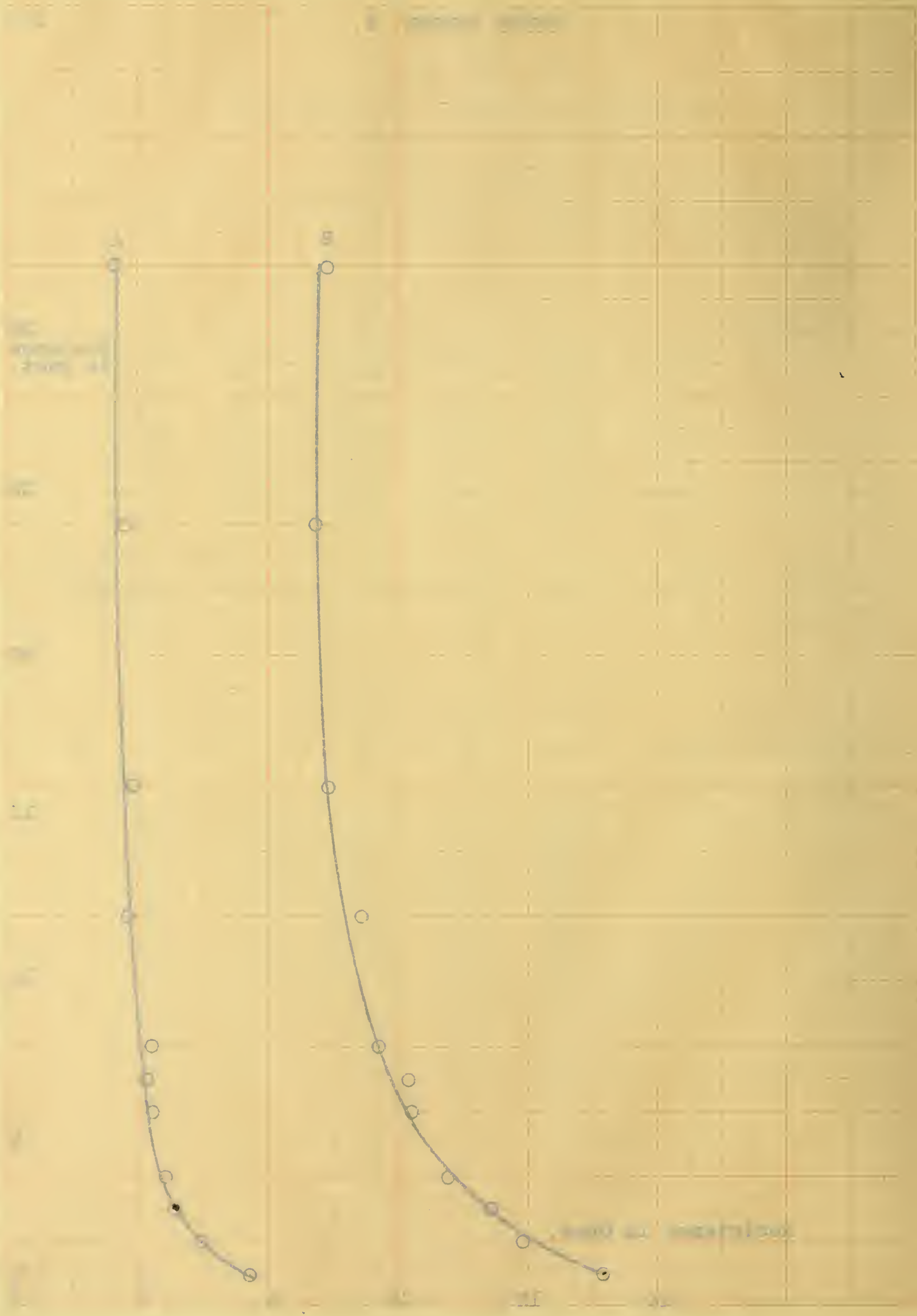
Pipe Number	4'-5'	3'-5'	5'-6'	4'-6'	1'-6'
Distance in Feet	8	12	16	24	31
Resistance in Ohms	10.06	----	9.26	9.05	9.22
	10.06	----	9.26	9.00	9.21
	10.11	----	9.28	9.08	9.30
	9.86	9.84	9.04	8.82	9.02
	9.93	9.87	9.07	8.87	9.06
	9.73	9.69	8.85	8.64	8.92
	9.42	9.40	8.64	8.52	8.66
	9.31	9.30	8.64	8.41	8.61
	9.25	9.24	8.52	8.36	8.52
Total	87.73	57.34	80.56	78.75	80.52
Average	9.75	9.56	8.95	8.75	8.95

CURVE NUMBER 5.



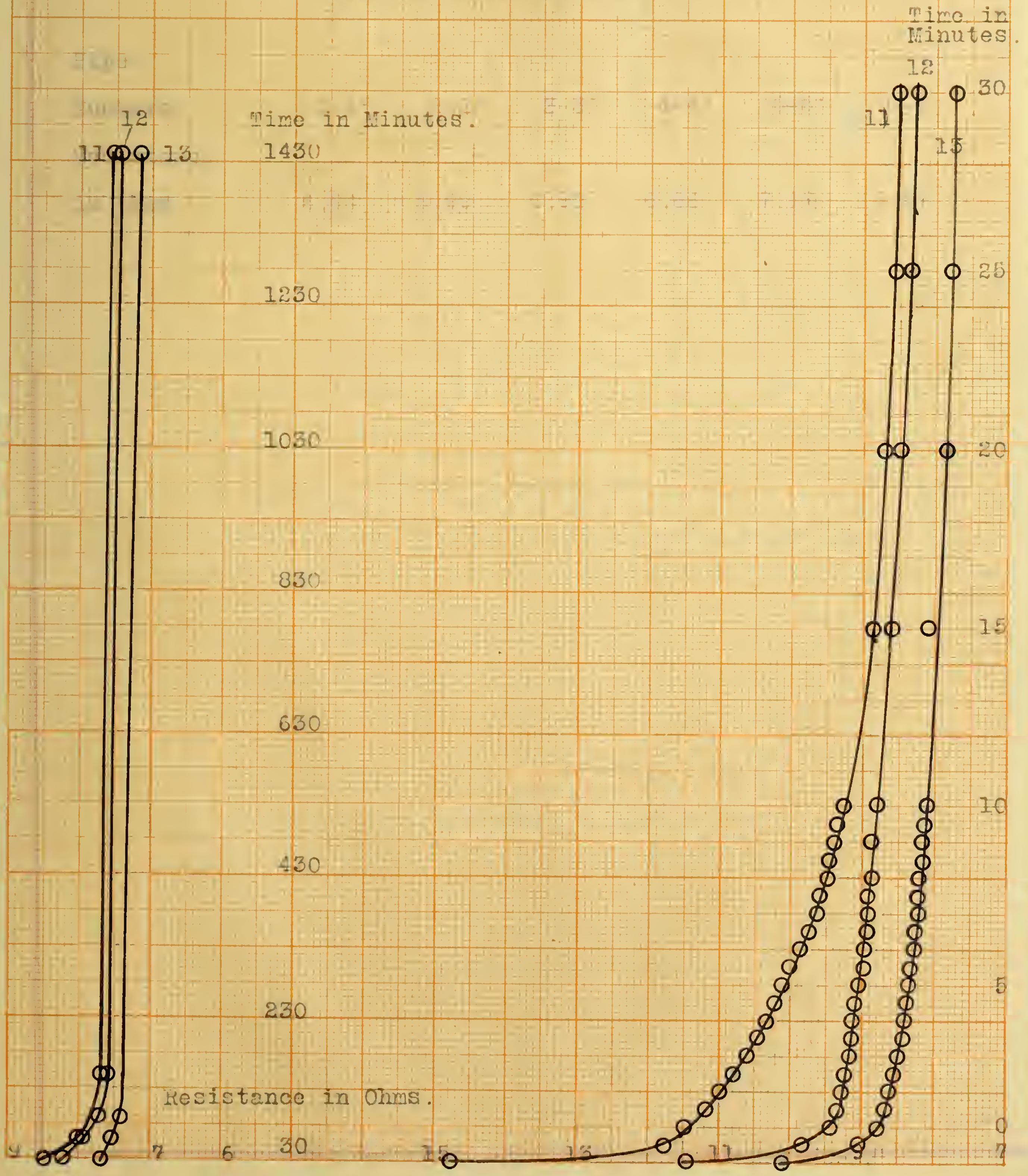

A
B

DATA FOR CURVE 6.

Variation of Resistance with Time After Salting.

Pipe Number	11	12	13	Pipe No.	11	12	13
Time in Minutes				Time in Min.			
Unsalted	14.76	11.46	10.18	7-1/2	9.63	8.94	8.23
1/2	11.78	9.83	9.03	8	9.51	8.93	8.21
1	11.50	9.45	8.80	8-1/2	9.46	----	8.19
3/2	11.17	9.35	8.69	9	9.40	8.20	7.96
2	11.02	9.34	8.65	9-1/2	9.38	----	8.12
2-1/2	10.82	9.26	8.56	10	9.26	8.82	8.11
3	10.62	9.20	8.51	15	8.87	8.65	8.11
3-1/2	10.48	9.17	8.43	20	8.72	8.52	7.89
4	10.36	9.15	8.41	25	8.56	8.36	7.80
4-1/2	10.22	9.10	8.39	30	8.50	8.28	7.71
5	10.11	9.06	8.37	60	7.94	8.01	7.58
5-1/2	10.02	8.99	8.33	90	7.75	7.75	7.42
6	9.86	8.99	8.30	120	7.76	7.64	7.58
6-1/2	9.76	8.99	8.29	150	7.74	7.61	----
7	9.67	8.98	8.25	180	7.71	----	----
				1440	7.46	7.54	7.19

CURVE NUMBER 6.



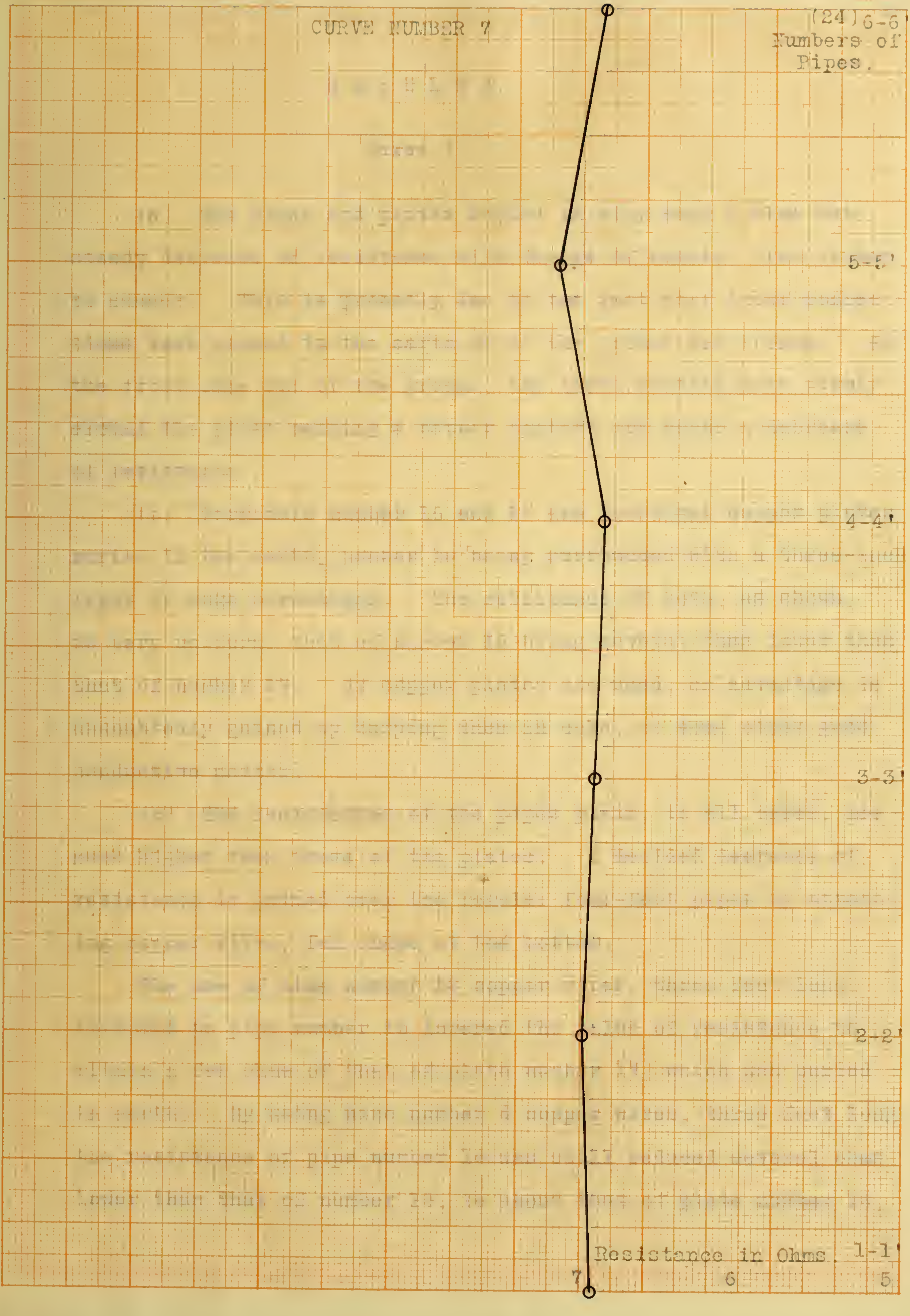
DATA FOR CURVE 7.

Variation of Resistance with Distance.

Pipes in Parallel to Ground.

Pipe Numbers.	1-1'	2-2'	3-3'	4-4'	5-5'	6-6'
Resistance in Ohms.	6.94	6.99	6.92	6.86	7.17	6.87

CURVE NUMBER 7



RESULTS.

Curve 1.

(a) The pipes and plates buried in clay show a slow but steady decrease of resistance with change of season, from winter to summer. This is probably due to the fact that these connections were placed in the earth while the ground was frozen. As the frost came out of the ground, the earth settled more firmly around the pipes causing a better contact and hence a decrease of resistance.

(b) Terminals number 16 and 17 are identical copper plates buried in the earth, number 16 being surrounded with a three-inch layer of coke screenings. The resistance of both, as shown, is very uniform, that of number 16 being several ohms lower than that of number 17. If copper plates are used, an advantage is undoubtedly gained by burying them in coke, or some other good conductive matter.

(c) The resistances of the pipes plain, in all cases, are much higher than those of the plates. A decided decrease of resistance is gained over the regular four-foot pipes by attaching copper wires, fan shape at the bottom.

The use of nine number 12 copper wires, three feet long, attached to pipe number 15 lowered the value of resistance to within a few ohms of that of plate number 17, which was buried in earth. By using nine number 4 copper wires, three feet long, the resistance of pipe number 14 was still reduced several ohms lower than that of number 15, to about that of plate number 16,

which was buried in coke. If the wires of pipe number 14 had been buried in coke, as was the plate, the resistance would have been the lowest of all the terminals. Under the best conditions, the resistance of the four-foot plain pipes is about ten ohms, while the resistance of the four-foot pipes with wires attached, is less than four ohms.

Curve 2.

The resistance of the ground increases very rapidly for increasing distance up to about twelve feet. For greater distances, the resistance is constant. This result is verified by the data taken for two separate sets of pipes in different parts of the plot of ground.

Curve 3.

From curve number 1, the one and two foot pipes show that there is no uniformity in their resistances, the variation being affected by existing weather conditions from day to day.

In general the resistance of the pipes decreases very rapidly for increase of length, from one foot to four feet, and for pipes longer than six feet there was little further decrease. This is due, in part, to the difference in area of contact, but the fact that the short pipes are buried in the upper loose loam also accounts for the higher resistance. The hard clay in which the longer pipes are buried, contains much moisture, insuring good contact due to the hard clay being firmly packed around the pipes.

The presence of moisture increases the conductivity and

hence lowers the resistance. It is probably this lower moist bed of hard clay which carries most of the current for circuits of any appreciable length; hence the better the contact with it, the less will be the resistance.

Curve 4.

In using four-foot lengths of standard iron pipe, the resistance shows a rapid decrease with increased size of pipe, up to about three inches. Beyond this size, the decrease in resistance is small as compared to the increase of first cost and installation of larger pipes.

Curve 5.

These curves for parallel circuits show that the resistance decreases rapidly with increase of the distance between pipes, up to about eight feet, after which the decrease is slow and gradual. This is due to the greater drop in the earth when the circuits are close together. The current density varies inversely with the distance between terminals, caused by the interference of stream lines between pipes.

Curve 6.

The effect of using artificial means to increase the conductivity of the earth and contact, is well shown in these curves. The resistance of the pipes after being salted immediately falls several ohms. The decrease of resistance is rapid for the first several minutes, more gradual for the next couple of hours, and about constant from then on.

Curve 7.

This test was run to show the uniformity of resistance with constant distance of 32 feet between pipes in parallel to ground. Six sets of pipes in parallel were used, the maximum variation of resistance being less than one-half ohm. From this, it is seen that the resistance of ground does not vary from east to west, but seems to vary uniformly from north to south.

CONCLUSIONS

These results show that the resistance decreases with:-

(a) The lower layers of soil.

(b) The addition of artificial matter of high conductivity.

(c) The distance between pipes in parallel, up to about twelve feet.

(d) The length of pipe, up to about six feet.

(e) The size of pipe, up to a diameter of about three inches. Also, that the resistance increases with the distance between pipes in series, up to about twelve feet.

From this, as to efficiency, cost, and durability, a pipe about six feet long with a diameter of about two inches, and having a number of large sized copper wires fanned out from bottom in coke, should be chosen. Two such connections used in parallel, at a distance greater than twelve feet, would reduce the resistance to about half of that of one. The application of a salt solution several times a year, would still further reduce the resistance.

A large copper plate, of the proper dimensions, buried in coke would give the same resistance as the above connection, but at ten to fifteen times the first cost.

This new method offered would greatly reduce the cost over the present method, of burying such expensive plates. Much further interesting data could be added to this thesis by additional readings of the resistance of the terminals for the balance of the year. This would show if the variations brought out here are uniform regardless of season.

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